Simulation of scheduling gains in LTE

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***Abstract*— This paper describes the implementation of an LTE downlink simulator that is able to precisely model the fast time and frequency variations existing in a multipath channel. This is decisive to properly simulate the gains achievable by the channel-dependent scheduling LTE is capable of. The aim of this study is to investigate the relationship between the throughput achieved by a base station and parameters of active users in the cell (such as SINR or speed). The ultimate goal is to obtain a model that can predict throughput as a function of a few selected parameters that characterize users' conditions. A proportional fair scheduler is used because of its ability to maximize the BS throughput while preventing user starvation. Some conclusions are drawn on the main parameters affecting the BS throughput based on results obtained so far.**

I. Introduction

Within the past two decades, the evolution of mobile communication networks has been unstoppable, with releases of new systems appearing every few years. All of them have brought in increased capabilities -essentially, *throughput*- in order to meet the raising urges of the customer base. In the late nineties *Wideband Code Division Multiplexed Access* (WCDMA) emerged as the technology the radio access network should rely on for the next decade. WCDMA is used in *third generation* (3G) mobile communications systems such as the *Universal Mobile Telecommunications System* (UMTS). Despite the new features and capacity enhancements added by its latest releases[1], the capacity of the system can hardly reach dozens of Mbps. The 3GPP *Long Term Evolution* (LTE) is the first *fourth generation* (4G) standard, and is called to be the successor to 3G systems and to improve its performance.

One of LTE's main features is the different approach to the use of the spectrum (compared to previous generations). It is based on the *orthogonal frequency-division multiplexing* (OFDM), which allows the network to allocate radio resources both in time and frequency. This, together with the use of *adaptive modulation and coding* (AMC) techniques, leads to a new level of flexibility when scheduling several *user equipment* (UE) devices. Thus, an improvement on the average throughput is obtained by the BS. To take full advantage of this scheduling flexibility it is therefore essential to know the detailed behavior of the channel, in other words: to characterize the channel as accurately as possible. This implies, of course, some heavy computational effort.

The target of this paper is to describe an LTE simulator capable of deploying a multi-user scenario involving one BS transmitting to different users. The simulator is able to accurately characterize all the propagation effects, mainly multipath propagation, so the scheduler can exploit the benefits of a fast time and frequency changing channel.

The ultimate goal of this whole project is to find a "link" between the BS throughput and a reduced set of relevant users' parameters such as speed, *signal-to-interference-plus-noise ratio* (SINR), etc. so that the BS throughput could be obtained just by knowing the values of those relevant parameters. High level LTE design suites could take advantage of these results and apply them in their inner calculations without performing low-level link simulations, hence improving accuracy whilst keeping computational expenses low. Specifically, the results obtained are meant to be included to the radio planning suite **Xirio-Online**, developed by **Aptica Consulting**, as a part of their strategy for keeping their products up with the latest technologies available in mobile communications.

The organization of the paper is as follows: in Section II reasons behind the realization of this project are given. In Section III a detailed description of the simulator is presented, with a short overview of the multipath propagation model used. In Section IV results obtained so far are shown, and Section V exposes conclusions drawn from the project.

II. Related works

As has been previously stated, one of the main advantages of LTE is that it can take advantage of the fast channel fluctuations that are due to multipath fading. The authors of this paper have found that many commercial LTE planning suites[2] are not actually simulating the multipath channel, therefore not accurately modelling all the "scheduling gain" LTE is capable of. The available documentation for all the examined suites has no mention to algorithms or channel models considering multipath fading. The approaches proposed (if any) are essentially the same: adding a fixed throughput gain to the one calculated using a round-robin scheduler. This work is aiming at filling this gap.

III. Model

The case study is focused on the downlink of a *frequency division duplex* (FDD), single carrier LTE system. The case-

[1] *High-Speed Downlink Packet Access* (HSDPA) in Rel. 5 and *High-Speed Uplink Packet Access* (HSUPA) in Rel. 6.

[2] The gorup of considered suites includes recent versions of: Atoll, Mentum Planet, Cellular Expert and ATDI CSI Telecom.

scenarios may vary between macrocell and microcell. Table 1 shows other configurable parameters.

The simulation process is based upon the following hypothesis and approximations:

- A single cell is simulated, which is considered enough to characterize the effects sought.
- The simulations should represent a time evolving channel.
- Different MIMO schemes are allowed.
- The following schedulers are considered: *proportional fair* (PF), *round-robin* (RR) and *max-SINR* (M-SINR) .
- Traffic modeling: full buffer. There is always data awaiting to be transmitted to a certain user when scheduled.
- In a first approach of the simulator only the downlink is considered. From a capacity perspective the downlink is far more interesting.
- *Hybrid automatic repeat request* (HARQ) gains are modelled by including them in the used *block error rate* (BLER) tables.

A. Simulator description

The simulator is implemented in Matlab and it is divided into two different parts: the core and the wrappers. The core consist of the files with the code that perform the actual calculations (channel coefficients, schedulers, etc). The wrappers are more heterogeneous pieces of code, some serve the purpose of easing the deployment of multiple simulations, while others are used to post-process the raw data, automate the information gathering and summarize it into easy-to-understand schemes.

All the parameters configurable by the user are shown in Table 1.

Input parameter	**Possible values**
Antenna schemes	$a \times b$, with a or $b \leq 2$
Scenario	Macro (outdoor), Micro (outdoor)
Number of UEs	any ≥ 0
Sampling time	any ≥ 0 (def: 2 ms)
Simulation lenght	any ≥ 0
Carrier frequency	0.8 GHz $\geq f \geq 5$ GHz
Frequency granularity	any (def: 180 kHz)
Speed for all the users	any ≥ 0
Scheduler	PF, RR or M-SINR

Table 1. Input parameters

B. Simulation work flow

Each simulation involves several different steps that can be summed up in the following list:

1) The user is prompted to configure all the required parameters
2) Average *signal to noise ratio* (SINR) is generated for each existing user from normal distributions (dB), with both mean and variance tailored to the chosen case-scenario. These SINR values should be understood as averages over fast multipath variations. The normal distributions are tuned to approximately match the distributions shown in [1]. Any user's SINR also defines its position within the cell coverage area.
3) Time and frequency changing multipath links are generated for each user (in the form of channel coefficients arranged in channel matrices), including the specified MIMO scheme (as explained in C).
4) Instant SINR is calculated from average SINR by using the previously gathered channel coefficients.
5) User computed *channel quality indicator* (CQI) is fed back to the BS so that the scheduler can use it. The feedback modeling is intended to be realistic: a few milliseconds delay is simulated and the granularity of the reports is several time-frequency slots (reporting a CQI for each time and frequency resource would be unrealistic). This causes the scheduler not to have "perfectly accurate" information. The specific parameters (time granularity and format) used for the CQI feedback is the "eNodeB-configured", as shown in [2] and [3].
6) The scheduler assigns time and frequency resources to each user. A PF scheduler has been selected as the main scheduler although RR and M-SINR approaches are also available.
7) When scheduling, the BS assigns a *modulation an coding scheme* (MCS) to each user for transmitting.
8) Steps 4 to 7 are repeated until the configured simulation duration is over.

C. Multipath fading and channel coefficients

The simulator relies on an underlying multipath channel model, the *3GPP Spatial Channel Model* (SCM) and its extension, the *3GPP Spatial Channel Model Extended* (SCME). Specifically, the Matlab implementations described in [4] and [5] have been used and integrated in the simulator.

As the authors state: "This channel model takes the *multiple-input multiple-output* (MIMO) radio link parameters, model configuration parameters and antenna parameters as inputs and outputs the MIMO channel matrices". Those channel matrices contain the channel coefficients for every possible spatial link (or *path*) between the base station and the user, for each user and for every time slot configured. A few subpaths within a path are also considered, each characterized by its unique delay value (named τ).

Before digging further into the mathematical aspects related to the processing of the SCME model output, we need to define some parameters:

- u refers to the index of each antenna element in the transmitting array (BS).
- s refers to the index of each antenna element in the receiving array (MS).
- k is the index of each user in the simulation.
- n is the index of each time sample in which the simulation will take place. Each time sample corresponds to 2 ms.
- b is the index for each available frequency subbands (frequency slots).
- d refers to the index of the existing delay subpaths.

- τ are the delay values associated to each d delay subpath.

From now on, the multidimensional channel matrix output by the SCME Matlab implementation will be denoted as $C_{u,s,k,n,d}$.

SCM and SCME implementations don't provide in an explicit way time and frequency channel coefficients (this is, the time-varying *frequency response* of the channel). Those models provide the impulse response of the channel, so some calculations need to be done from the data these actually provided. Time and frequency channel matrices are thus obtained by applying the Fourier Transform (with respect to the delay variable, τ) to the channel matrix ($C_{u,s,k,n,d}$), as is depicted in eq. 1.

$$H_{n,b} = \begin{pmatrix} h_{1,1} & \cdots & h_{1,b} \\ \vdots & \ddots & \vdots \\ h_{n,1} & \cdots & h_{n,b} \end{pmatrix} = \\ = C_{n,d} \begin{pmatrix} e^{-2j\pi f_1 \tau_1} & \dots & e^{-2j\pi f_b \tau_1} \\ \vdots & \ddots & \vdots \\ e^{-2j\pi f_1 \tau_d} & \dots & e^{-2j\pi f_b \tau_n} \end{pmatrix} = \\ = \begin{pmatrix} c_{1,1} & \cdots & c_{1,d} \\ \vdots & \ddots & \vdots \\ c_{n,1} & \cdots & c_{n,d} \end{pmatrix} \begin{pmatrix} e^{-2j\pi f_1 \tau_1} & \dots & e^{-2j\pi f_b \tau_1} \\ \vdots & \ddots & \vdots \\ e^{-2j\pi f_1 \tau_d} & \dots & e^{-2j\pi f_b \tau_n} \end{pmatrix} \quad (1)$$

where the matrix populated with $c_{n,d}$ coefficients results from the matrix $c_{u,s,k,n,d}$ when selecting specific values for k (a particular user), u and s (the latter two represent one of the possible paths between the BS and user antenna elements). $\{f_1 \quad \dots \quad f_b\}$ represent the set of considered frequency values. The frequency axis is created around the carrier frequency selected when setting up the simulator. Each step between these values is fixed to be equal to a certain amount (between 1 and several) of *resource blocks* (RB). There is a tradeoff here: the more the frequency granularity in the channel simulation, the heavier the computation is (specifically in terms of required memory). The authors have found that a step of 8 RB made a huge improvement in performance causing only a small reduction in accuracy.

Let $H_{u,s,k,n,b}$ be the multidimensional channel matrix that comes from repeating the calculation made in eq. 1, for every user k, and every possible path between transmitter and receiver antenna elements (u, s). For each combination of u, s, and k a specific $H_{n,b}$ is obtained.

Once the time and frequency channel coefficients are known, the next step is to determine the actual SINR the users have at every instant (and in frequency as well). Assuming MIMO has been included in the analysis, two possible cases are evaluated (either one or the other, defined by the *rank indicator*, may occur depending on the later calculations the BS makes with the fed back CQI):

- The system uses **diversity** to transmit to the user.
- The system uses two spatial channel to transmit to the user (actual 2 × 2 MIMO).

In the first case, the channel coefficients associated to each link between the user and the BS are added in the form of absolute square values. Eq. 2 shows this. This, essentially, represents a *maximal-ratio combining* (MRC) technique as described in [6].

$$C1_{k,n,b} = \sum_{u=0}^{U} \sum_{s=0}^{S} |C_{u,s,k,n,b}|^2 \quad (2)$$

In the second case, the channel coefficients are calculated by applying the *singular value decomposition* (SVD) technique [6] to the appropriate channel coefficient matrix, described in eq. 3.

$$C2_{mm,k,n,b} = SVD(|C_{k,n,b}|^2) \quad (3)$$

D. Scheduling and throughput calculations

This is the most computing intensive part of the simulator. M-SINR, RR and PF schedulers are available, while only the latter two are being actually used. The data that actually matters is the one provided when simulating with the PF scheduler whereas the RR scheduler is used —in a first approach— for comparative and testing purposes. The M-SINR is not used because it might cause starvation to some users.

The **round-robin** scheduler is fairly simple: there are fixed time slots and the users are scheduled in order, obtaining the same number of slots. The scheduled user takes the whole frequency band in a given time slot.

The **proportional fair** scheduler is built around the metric stated in eq. 4:

$$P_u^s = \frac{\mathrm{TDA}_u^s}{\widetilde{R_u}} \quad (4)$$

where P_u^s is the priority of the user u in the subband S, TDA_u^s is the achievable throughput by the user u in the subband S and $\widetilde{R_u}$ is the filtered throughput of the user u. A more extensive description of the PF scheduler can be found in [3]. This calculation is made at every time slot.

Fig. 1 shows an example of how the PF scheduler assings time and frequency slots to a group of users.

As eq. 5 illustrates, each user's throughput is obtained from MCS and BLER values.

$$\mathrm{Th} = (1 - \mathrm{BLER}) \cdot \mathrm{Th}_{\mathrm{raw}} \quad (5)$$

Th refers to the final throughput and Th_{raw} is the theoretical (raw) throughput, which is obtained from the MCS value.

Keeping in mind that a certain user may be allocated in several subbands at a given time slot, the MCS is obtained by calculating the average CQI along all the user-reported CQI values per subband, and then mapping this average CQI to an MCS value. The BLER value is calculated in a similar way: an *exponential effective SINR mapping* (EESM) calculation is performed over all the existing SINR values in the scheduled subbands, and then mapped to a BLER value by using the

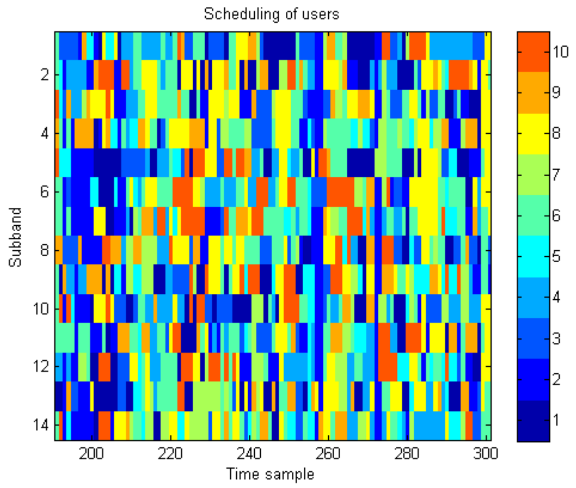

Fig. 1. Example of 10 users scheduled over a short time in a microcell scenario

static curves shown in [7]. The chosen EESM implementation is the one suggested by [8] and [9].

IV. Results

The project this paper describes is, at the time of writing the document, an ongoing project. Despite this fact, some outcomes have been gathered from the work done so far. In Fig. 2 a part of the results is shown. The throughput results obtained by several[3] BS is presented as a function of the mean and the standard deviation of the users' SINR values. It is interesting to note that the throughput pattern shown roughly repeats all over the sets of simulations performed no matter the parameters selected.

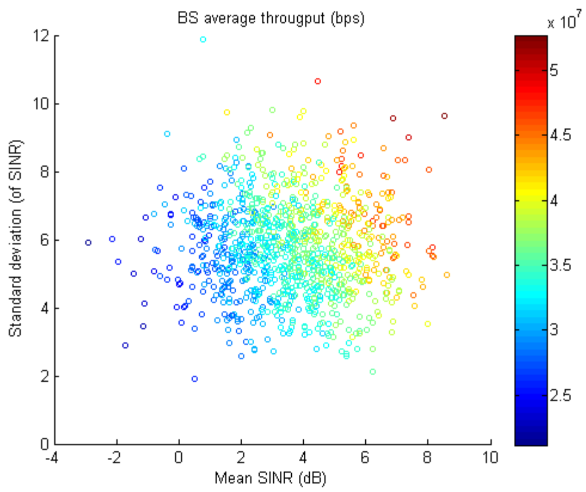

Fig. 2. BS throughput scatterplot distribution. 10 users over a macrocell scenario

[3]The number of simulations done with a given set of parameters is usually around a thousand simulations. This is considered enough to extract relevant data. Perform all the simulations takes usually 5 or 6 days of computing.

V. Conclusions and Future Work

After studying the data gathered from the extensive simulations some patterns are revealing:

- The number of active users in the cell affects the throughput of the base station, but in a lesser way than expected. The tested number of users has been 3 and 10.
- Mean SINR clearly affects the BS throughput. This was of course an expected result because of the ACM and scheduling techniques implemented in the simulator.
- Mean SINR does not completely determine the BS throughput. This was expected, because there is other phenomena that may affect capacity. For example: with a given SINR, the fact of the users' SINR being more disperse can produce a bigger throughput because the scheduler resource allocation is biased to the users with better propagation conditions.

This set of conclusions shows a more specific line of research, allowing us to go more in depth in the study of some parameters and their relation to the BS throughput.

Future work may include adapting the simulator to the new iteration of LTE, LTE Rel.10, known as *LTE-Advanced* (LTE-A). This implies adding new features like higher-order MIMO support and *carrier aggregation* (CA). Other plausible upgrade could be adding a user interface to use the simulator in a more simplified way.

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